SOME MODERN EXPLOSIVES.[1]

II.

I NOW pass to points which have to be considered when weighing the comparative merits of explosives for their intended ends.

You will easily understand that between explosives which are intended to be used for propelling purposes, and those which are intended to be used, say for bursting shell, a wide difference may exist.

In the former case, facility of detonation would be an insuperable objection; in the latter, the more perfect the detonation the better, certain special cases, to which I have not time to refer, excepted.

There exists, I think, considerable diversity of opinion as to what does, and what does not, constitute true detonation. I find many persons speak of a detonation, when I should merely consider that a very high pressure had been reached. This gun-cotton slab on the table affords me, I think, a fair opportunity of explaining my meaning. Were I to set fire to it, except for the large volume of flame and the great amount of heat generated, we in this room would not suffer; we should probably experience more inconvenience did I fire a similar slab of gunpowder, as detached burning portions would probably be projected to some distance.

But if I fired this same slab with two or three grammes of fulminate of mercury, a detonation of extreme violence would follow. The detonation would be capable of blowing a hole in a tolerably thick iron plate, and would probably put an end to a considerable portion of the managers in the front row.

I mentioned to you some time ago the time in which a charge would be consumed in the chamber of a gun—if a charge of 500 lbs. of these slabs were effectively detonated, this charge would be converted into gas in less than the 20,000th part of a second.

No such result would follow were I to try a similar experiment with a slab of compressed gunpowder of the same dimensions. I do not say the experience would be pleasant, but there would be nothing of the instantaneous violent action which marks the decomposition of the gun-cotton.

To give you an idea of the extraordinary violence which accompanies detonation, I have fired, for the purpose of this lecture, with fulminate of mercury, a charge of lyddite in a cast-iron shell, and those who are sufficiently near can see for themselves the result. By far the greater part of the cast-iron shell, weighing about 10 lbs., is reduced to dust, some of which is so fine that I assumed it to be deposited carbon until I had tested it with a magnet. I may add that the indentation of the steel vessel by pieces of the iron which were not reduced to powder would appear to indicate velocities of not less than 1200 feet-seconds, and this velocity must have been communicated to the fragments in a space of less than two inches.

For the sake of comparison, I place beside it a cast-iron shell burst by gunpowder. You will observe the extraordinary difference. I also have on the table two small steel shells exploded, one by a perfectly detonated, the other by a partially detonated charge. I may remark that in the accounts of correspondents from the seat of war, frequent mention is made of the green smoke of lyddite. This appearance is due probably to imperfect detonation—to a mixture, in fact, of the yellow picric with the black smoke. I do not say, however, that imperfect detonation is necessarily an evil.

To another experiment I draw your attention.

For certain purposes I caused to be detonated, in the chamber of a 12-pounder, a steel shell charged with lyddite. The detonation was not perfect, but the base of the shell was projected with great violence against the breech screw. You may judge of how great that violence was when I tell you that the base of the shell took a complete impression of the recess for the primer, developing great heat in so doing; but, what was still more remarkable, the central portion of the base also sheared, passing into the central hole through which the striker passes. This piece of shell is upon the table, and open to your inspection.

One other instance to illustrate the difference between combustion and detonation I trouble you with. Desiring to ascertain the difference, if any, in the products of explosion between combustion and detonation, I fired a charge of lyddite in such a manner that detonation did not follow. The lyddite merely deflagrated. But a similar charge differently fired shortly afterwards detonated with such extreme violence as to destroy the vessel in which it was exploded. The manner in which the vessel failed I now show you (Fig. 4), and I have on the table the internal crusher gauge which was used, and which was also totally destroyed.

The condition of this gauge is very remarkable, and the action on the copper cylinder employed to measure the pressure was one to which I have no parallel in the many thousand experiments I have made with these gauges. The gauge itself is fractured in the most extraordinary way, even in some places to which the gas had no access, and the copper cylinder, which when compressed usually assumes a barrel-like form (that is, with the central diameter larger than that at the ends as shown in Fig. 5); but in this experiment, and in this only, the cylinder was bulged closed to the piston, as you see. It would appear as if the blow was so suddenly given that the laminæ of the metal next the piston endeavoured to escape in the direction of least resistance, that being easier than to overcome the inertia of the laminæ below.

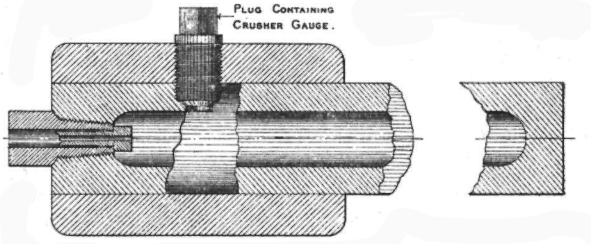

FIG. 4.—Explosion vessel.

The erosive effect of the new explosives is another point of first-rate importance in an artillery point of view. The cordite of the service is not, if the effect be estimated in relation to the energy impressed on the projectiles, more erosive than, for example, brown prismatic, which was itself a very erosive powder; but as we are able to obtain, as you have seen, very much higher energies with cordite than with brown prismatic, the erosion of the former is, for a given number of rounds, materially higher.

There is, however, one striking difference. By the kindness of Colonel Bainbridge, the Chief Superintendent of Ordnance Factories, I am enabled to show you a section of the barrel of a large gun eroded by 137 rounds of gunpowder. Beside it is a barrel of a 4·7-inch quick-firing gun eroded by 1087 rounds of gunpowder, and another eroded by 1292 rounds of cordite. You will observe the difference. In the former case the erosion much resembles a ploughed field. In the latter the appearance is more, as if the surface were washed away by the flow of the highly heated gases.

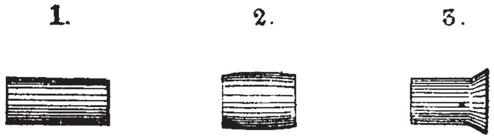

FIG. 5.—Copper cylinders.

But take it in what way you please, the heavy erosion of the guns of the service, if fired with the maximum charges, is a very serious matter, as with the large guns, accuracy, and in a smaller degree energy, are rapidly lost after a comparatively small number of rounds have been fired.

Cordite was first produced for use in small arms only, where, owing to the small charges employed, the question of erosion is not of the same importance as with large guns; but its employment, from the great results obtained with it, was rapidly extended to artillery, and the attention of my friends, Sir F. Abel and Prof. Dewar, has for some time been devoted in conjunction with myself to investigating whether it is not possible materially to reduce this most objectionable erosion.

With this object I made the following series of experiments.

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[1] A Discourse delivered at the Royal Institution on Friday, March 23, by Sir Andrew Noble, K.C.B., F.R.S. Continued from p. 90.

I had cordite of the same dimensions prepared with varying proportions of nitro-glycerine and gun-cotton. The nitro-glycerine being successively in the proportions of 60, 50, 40, 30, 20 and 10 per cent., and with each of these cordites I determined the following points :—

(1) The quantity of permanent gases generated.
(2) The amount of aqueous vapour formed.
(3) The heat generated by the explosion.

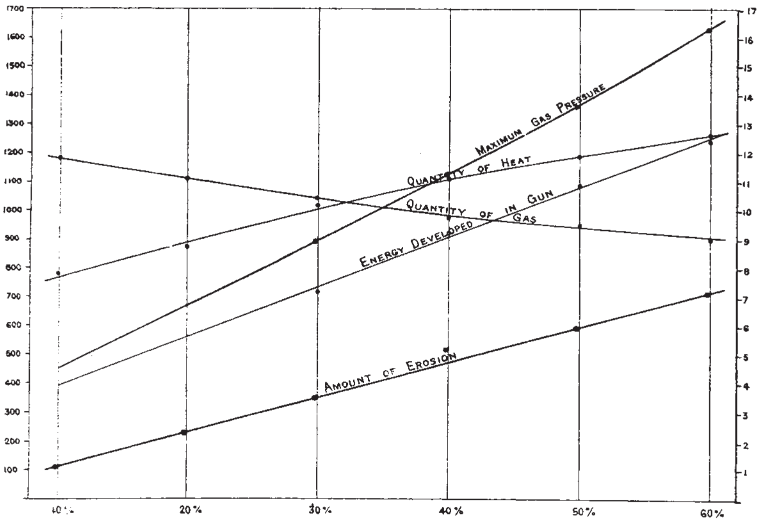


FIG. 6.—Energy in foot tons ; heat in units ; gas in c.c. ; erosion in inches ; pressure in tons.

(4) The erosive effect of the gases.
(5) The ballistic energy developed in a gun, and the corresponding maximum pressure.
(6) The capacity of the cordite to resist detonation when fired with a strong charge of fulminate of mercury.

The results of these experiments were both interesting and instructive.

To avoid wearying you with a crowd of figures, I have placed on Fig. 6 the results of the first five series of experiments.

On the axis of abscissæ are placed the percentages of nitro-glycerine, while the ordinates show the quantities of the gases generated, the amount of heat developed, the erosive effect of the explosive, the ballistic energy exhibited in a gun, and the maximum gaseous pressure.

You will note that with the smallest proportion of nitro-glycerine the volume of permanent gases is a maximum, and that the volume steadily decreases with the increase of nitro-glycerine. On the other hand, the heat generated as steadily increases with the nitro-glycerine, and if we take the product of the quantity of heat and the quantity of gas as an approximate measure of the potential energy of the explosive, the higher proportion of nitro-glycerine has an undoubted advantage ; but in this case, as in the case of every other explosive with which I have experimented, the potential energies differ less than might be expected from the changes in transformation, as the effect of a large quantity of gas is to a great extent compensated by a great reduction in the quantity of heat generated.

This effect is, of course, easily explained, and was very strikingly exhibited in the much more complicated transformation experienced by gunpowders of different compositions, a long series of which were very fully investigated by Sir F. Abel and myself.

Looking at this diagram you will have observed that the energy developed in the gun is very much smaller with the smaller proportions of nitro-glycerine, but if you will look at the corresponding maximum pressure-curve you will note that the pressures have decreased nearly in like proportion. Hence it is probable that the lower effect is mainly due to a slower combustion of the cordite, and it follows that this effect may be, to a great extent, remedied by increasing the rate of combustion by reducing the diameter of the cordite to correspond with the reduction in the quantity of nitro-glycerine.

To test this point I caused to be manufactured a second series of cordites of the same composition, but with the diameters successively reduced by ·03, as you see with the samples I hold, and this diagram (Fig. 7) shows at a glance the result. The energies you see are, roughly, practically the same, but if you look at the pressure-curve you will observe that I have obtained a curve in which, on the whole, the pressures vary in the contrary direction, that is to say, in this case the pressures increase as the nitro-glycerine diminishes.

Taking the two series into account, they show that by a proper arrangement of amount of charge and diameter of cord it would be possible to obtain the same ballistics and approximately the same pressure from any of the samples I have exhibited to you.

But I have to draw your attention to another point. From the curve showing the quantities of heat you will note that in passing from 10 per cent. nitro-glycerine to 60 per cent., the heat generated has increased by about 60 per cent. But here is the curve indicating the corresponding amount of erosion, and you will see that while the quantity of heat is only greater by about 60 per cent., the erosion is greater by nearly 500 per cent.

These experiments entirely confirm the conclusion at which I have previously arrived, viz. that heat is the principal factor in determining the amount of erosion.

In experimenting with a number of alloys of steel, the greatest resistance was shown by an alloy of steel with a small proportion of tungsten, but the difference between the whole of these amounted only to about 16 per cent.

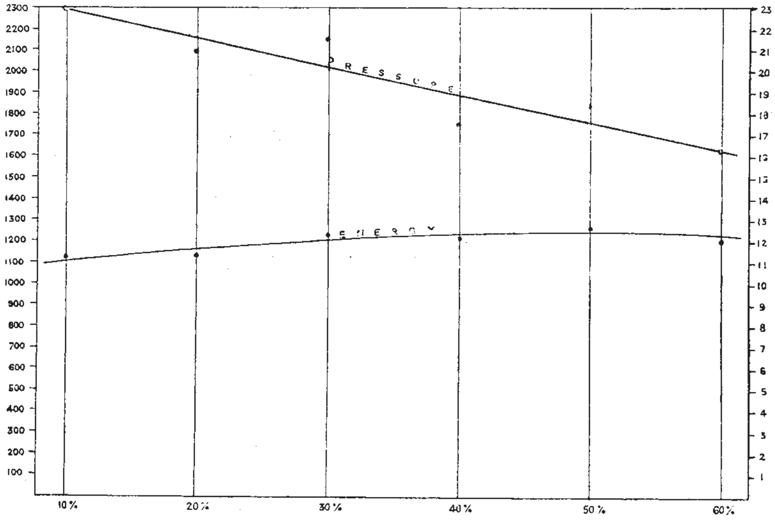


FIG. 7.—Energy in foot tons ; pressure in tons.

The whole of these cordites were, as I have mentioned, subjected to detonation tests. None of them, so far as my experiments went, exhibited any special tendency in this direction.

I will now endeavour to describe to you a most interesting and important series of experiments which, I regret to say, is a long way from completion.

The objects of these experiments were (1) to ascertain the time required for the combustion of charges of cordite in which the cordite was of different thicknesses, varying from 0·05 inch to 0·60 of an inch; (2) the rapidity with which the explosives part with their heat to the vessel in which the charge is confined; and (3) to ascertain, if possible, by direct measurement, the temperature of explosion, and to determine the relation between the pressure and temperature at pressures approximating to those which exist in the bore of a gun, and which are, of course, greatly above any which have yet been determined.

As regards the first two objects I have named, I have had no serious difficulties to contend with, but as regards the third, I have so far had no satisfactory results, having been unable to use Sir W. Roberts Austen's beautiful instrument owing to the temperature at the moment of explosion being greatly too high, high enough indeed to melt and volatilise the wires.

I am, however, endeavouring to make an arrangement by which I hope to be able to determine these points when the temperature is so far reduced that the wires will no longer be fused.

If the piston be left free to move the instant of the commencement of pressure, the outside limit of the time of complete explosion will be indicated; but, on account of the inertia of the moving parts, the pressure indicated will be in excess of the true pressure, and the excess will be, more or less, inversely as the time occupied by the explosion.

If we desire to know the true pressure, it is necessary to compress the gauge beforehand to a point closely approximating to the expected pressure, so that the inertia of the moving parts may be as small as possible—the arrangement by which this is effected is not shown in the photograph, but the gauge is retained at the desired pressure by a wedge-shaped stop, held in its place by the pressure of the spring, and to the stop a heavy weight is attached—when the pressure is relieved by the explosion, the weight falls and leaves the spring free to act.

I have made a large number of experiments with this instrument, both with a variety of explosives and with explosives fired under different conditions. Time will not permit me to do more than to show you on the screen three pairs of experiments to illustrate the effect of exploding cordite of different dimensions, but of precisely the same composition.

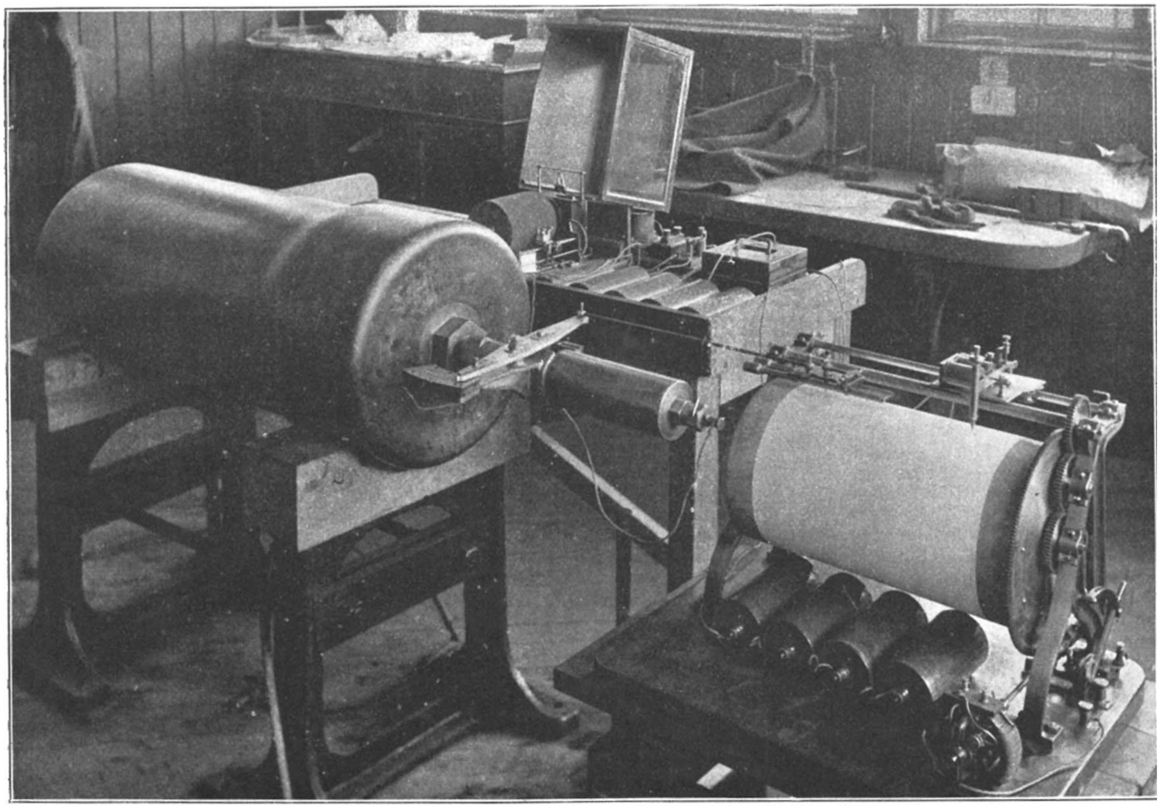


FIG. 8.

The apparatus I have used for these experiments is placed on the table. The cylinder in which the explosives were made is too heavy to transport here, but this photograph (Fig. 8) will sufficiently explain the arrangement. The charge I used is a little more than a kilogramme, and it is fired in this cylinder in the usual manner.

The tension of the gas acting on the piston compresses the spring, and indicates the pressure on the scale here shown. But to obtain a permanent record, the apparatus I have mentioned is employed.

There is, you see, a drum made to rotate by means of a small motor. Its rate of rotation is given by a chronometer acting on a relay, and marking seconds on the drum, while the magnitude of the pressure is registered by this pencil actuated by the pressure-gauge I have just described.

To obtain with sufficient accuracy the maximum pressure, and also the time taken to gasify the explosive, two observations—that is, two explosions—are necessary.

I shall commence with rifle cordite. In this diagram (Fig. 9) the axis of abscissæ has the time in seconds marked upon it, while the ordinates denote the pressures, and I draw your attention to the great difference, in the initial stage, between the red and the blue curves. You will notice that the red curves show a maximum pressure some 4½ tons higher than that shown by the blue curve; but this pressure is not real. It is due to the inertia of the moving parts. The red and blue curves in a very small fraction of a second come together, and remain practically together for the rest of their course. The whole of the charge is consumed in something less than fifteen thousandths (·015) of a second.

In the case of the blue curve the maximum pressure indicated is obtained in the way I have described, and is approximately correct—about nine tons per square inch. The rapidity with which this considerable charge parts with its heat by communication to the explosion vessel is very striking. In four seconds after the explosion the pressure is reduced to about one-half, and in twelve seconds to about one-quarter.

I now show you (Fig. 10) similar curves for cordite 0·35 inch in diameter, or about fifty times the section. Here you see that the time taken to consume the charge is longer. The effect of inertia is still very marked, although much reduced. The true maximum pressure is little over 8·5 tons, but after the first third of a second the two curves run so close together that they are indistinguishable.

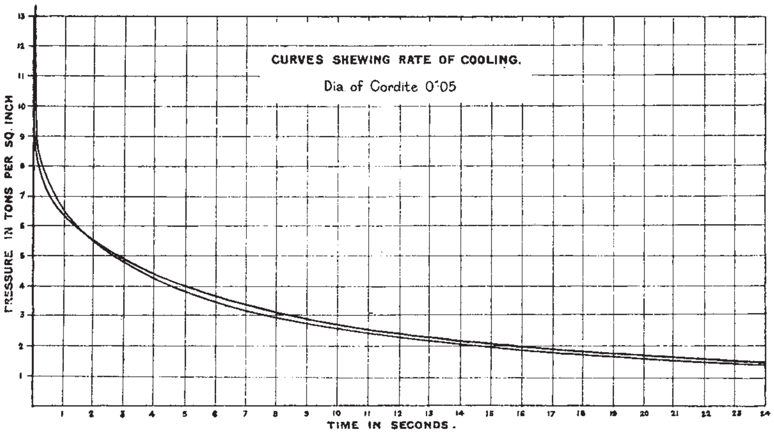


FIG. 9.

Again, you see the pressure is reduced by one-half in four seconds, and in a little more than twelve seconds again halved.

The last pair of curves I shall show (Fig. 11) you was obtained with cordite 0·6 inch in diameter, or nearly 150 times the section of the rifle cordite. With this cordite the combustion has been so slow that the effect of inertia almost disappears; it is reduced to about half a ton per square inch. The maximum being nearly the same as in the last set of experiments. The time of combustion indicated I have called slow, but it is about ·06 of a second, and the whole of the experiments show a most remarkable regularity in their rate of cooling, the pressures at the same distance of time from the explosion being in all cases approximately the same—as, indeed, they ought to be. The density being the same and the explosive the same, the only difference being the time in which the decomposition is completed.

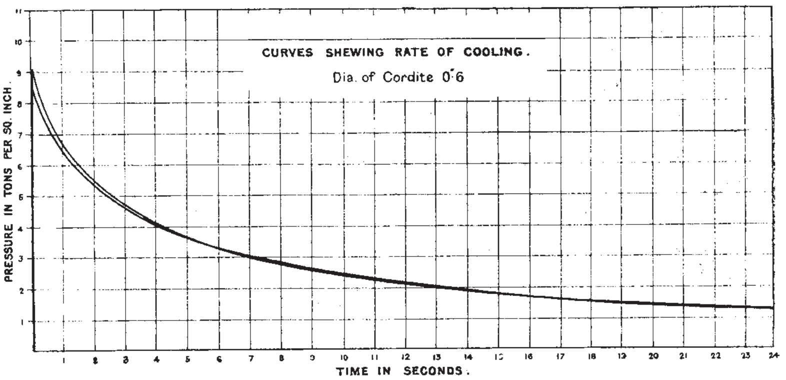


FIG. 11.

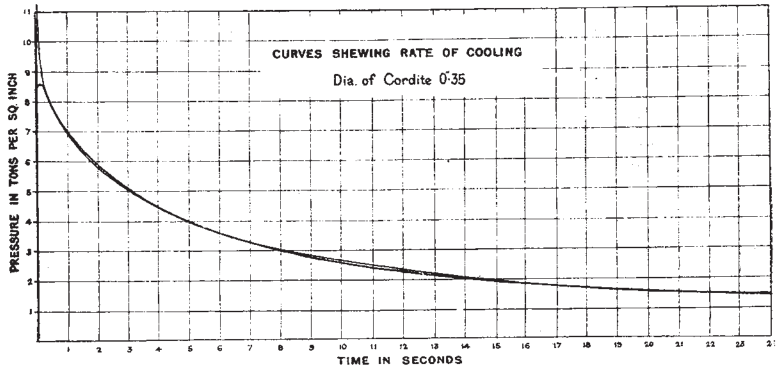


FIG. 10.

It appears to me that, knowing from the experiments I have described, the volume of gas liberated, its composition, its density, its pressure, the quantity of heat disengaged by the explosion; and knowing all these points with very considerable accuracy, we should be able, from the study of the curves to which I have drawn your attention, and which can be obtained from different densities of gas, to throw considerable light upon the kinetic theory of real, not ideal gases, at temperatures and pressures far removed from those which have been the subject of such careful and accurate research by many distinguished physicists.

The question, as I have said, involves some very considerable difficulties; nevertheless, I am not without hope that the experiments I have been describing may, in some small degree, add to our knowledge of the kinetic theory of gas.

That wonderful theory faintly shadowed forth almost from the commencement of philosophic thought, was first distinctly put forward by Daniel Bernoulli early in the last century. In the latter half of the century now drawing to a close the labours of Joule, Clausius, Clerk Maxwell, Lord Kelvin and others have placed the theory in a position analogous and equal to that held by the undulatory theory of light.

The kinetic theory has, however, for us artillerists a special charm, because it indicates that the velocity communicated to a projectile in the bore of a gun is due to the bombardment of that projectile by myriads of small projectiles moving at enormous speeds, and parting with the energy they possess by impact to the projectile.

There are few minds which are not more or less affected by the infinitely great and the infinitely little.

It was said that the telescope which revealed to us infinite space was balanced by the microscope which showed us the infinitely small; but the labours of the men to whom I have referred have introduced us to magnitudes and weights infinitesimally smaller than anything that the microscope can show us, and to numbers which are infinite to our finite comprehension.

Let me draw your attention again to this figure (Fig. 2) showing the velocity impressed upon the projectile, and let me endeavour to describe the nature of the forces which acted upon it to give it its motion. I hold in my hand a cubic centimetre, a cube so small that I daresay it is hardly visible to those at a distance. Well, if this cube were filled with the gases produced by the explosion at 0° C. and atmospheric pressure, there would be something over seven trillions, that is, seven followed by eighteen cyphers, of molecules. Large as these numbers are, they occupy but a very small fraction of the contents of the cubic centimetre, but yet their number is so great that they would, if placed in line touching one another, go round many times the circumference of the earth, a pretty fair illustration of Euclid's definition of a line.

These molecules, however, are not at rest, but are moving, even at the low temperature I have named, with great velocity, the molecules of the different gases moving with different velocities dependent upon their molecular weight. Thus, the hydrogen molecules which have the highest velocity move with about 5500 feet-seconds mean velocity, while the slowest, the carbonic anhydride molecules, have only 1150 feet-seconds mean velocity, or about the speed of sound.

But in the particular gun under discussion, when the charge was exploded there were no less than 20,500 cubic centimetres of gas, and each centimetre at the density of explosion contained 580 times the quantity of gas—that is, 580 times the number of molecules that I mentioned. Hence the total number of molecules in the exploded charge is $8\frac{1}{3}$ quadrillions, or let us say approximately for the total number eight followed by twenty-four cyphers.

It is difficult for the mind to appreciate what this immense number means, but it may convey a good idea if I tell you that if a man were to count continuously at the rate of three a second, it would take him 265 billions of years to perform the task of counting them.

So much for the numbers; now let me tell you of the velocities with which, at the moment of explosion, the molecules were moving. Taking first the high-velocity gas, the hydrogen, the molecules of the gas would strike the projectile with a mean velocity of about 12,500 feet-seconds. You will observe I say mean velocity, and you must note that the molecules move with very variable velocities. Clerk Maxwell was the first to calculate the probable distribution of the velocities. A little more than one-half will have the mean velocity or less, and about 98 per cent. will have 25,000 feet-seconds or less. A very few, about one in 100 millions, might reach the velocity of 50,000 feet-seconds.

The mean energy of the molecules of different gases at the same temperature being equal, it is easy from the data I have given to calculate the mean velocity of the molecules of the slowest moving gas, carbonic anhydride, which would be about 2600 foot-seconds.

I have detained you, I fear, rather long over these figures, but I have done so because I think they throw some light upon the extraordinary violence that some explosives exhibit when detonated. Take, for instance, the lyddite shell exploded by detonation I showed you earlier in the evening. I calculate that that charge was converted into gas in less than the 1/60,000th part of a second, and it is not difficult to conceive the effect that these gases of very high density suddenly generated, the molecules of which are moving with the velocities I have indicated, would have upon the shell.

The difference between the explosion of gunpowder fired in a close vessel, and that of gun-cotton or lyddite when detonated, is very striking. The former explosion is noiseless, or nearly so. The latter, even when placed in a bag, gives rise to an exceedingly sharp metallic ring, as if the vessel were struck a sharp blow with a steel hammer.

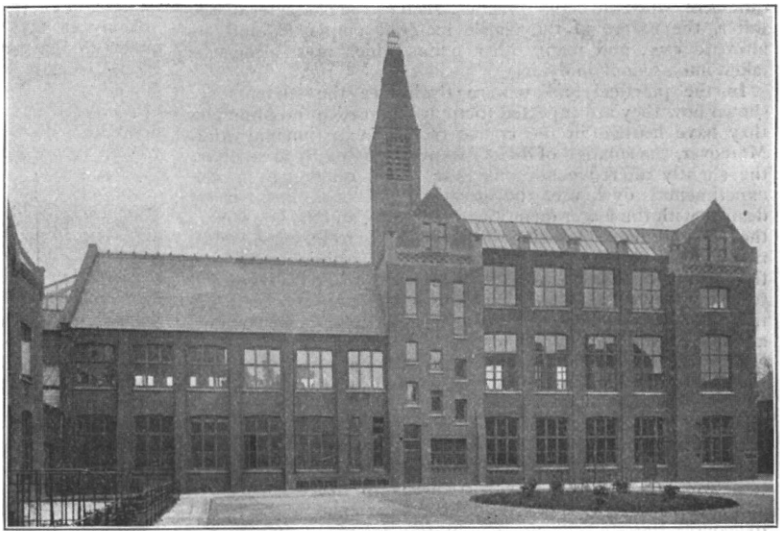
But I must conclude. I began my lecture by recalling some of the investigations I described in this place a great many years ago. I fear I must conclude in much the same way as I then did, by thanking you for the attention with which you have listened to a somewhat dry subject, and by regretting that the heavy calls made on my time during the last few months have prevented my making the lecture more worthy of my subject and of my audience.

EXTENSIONS OF THE DYEING DEPARTMENT OF YORKSHIRE COLLEGE.

THE opening of the extensions in the Clothworkers' Departments of Yorkshire College, Leeds, has already been referred to (p. 69). The new buildings, which are shown in the accompanying illustration, comprise practical and pattern dye-houses and a research laboratory; and, as with several other parts of Yorkshire College, they owe their erection to the generous interest taken in technical education by the Clothworkers' Company of London.

The Clothworkers' Departments of the Yorkshire College consist of textile industries, dyeing and art. The buildings occupied by these departments have been erected by the Clothworkers' Company at a cost of about 60,000*l.*; they are spread over an area of about one-and-a-half acres, and have been specially arranged and equipped for the teaching of all the subjects connected with the designing and manufacturing of woven fabrics.

The Dyeing Department of the Yorkshire College was established in 1880, and the head of the department is Prof. J. J. Hummel. Although the accommodation at first provided was extremely limited, it nevertheless sufficed to show that a demand for instruction in dyeing really existed, and that a continuous supply of students for this subject was available. In due time it was found desirable to increase the facilities for experimental work, and in 1885 the Clothworkers' Company of London erected and equipped, at an expense of about 12,000*l.*, the front portion of the handsome and commodious building at present occupied.



New Buildings of the Dyeing Department of Yorkshire College.

It was felt some years ago that the work of the different departments might be connected. It was considered desirable, for example, that the coloured yarns employed in the weaving department should be dyed by the students in the dyeing department, so that, if at the same time these yarns could also be manufactured on the premises by the establishment of a spinning department, it would become possible to teach the whole routine of clothworking, from the wool in the raw state to the finished cloth. Acting upon this idea, the Clothworkers' Company decided to make the necessary provision for carrying out the scheme suggested, and to extend both the weaving and dyeing departments, at a cost of about 25,000*l.* In connection with the dyeing department, it was arranged to build a three-storied building, to provide two additional dyehouses in which practical dyeing could be carried on, and also a research laboratory for the prosecution of scientific investigations connected with dyestuffs and dyeing.

In July 1896, the foundation stone of the new Clothworkers' Research Laboratory and the other extensions was laid by the